Journal of Forestry Research (2012) 23(1): 75–80
DOI 10.1007/s11676-012-0235-7

ORIGINAL PAPER

Assessing impact of climate change on forest cover type shifts in Western Himalayan Eco-region

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Received: 2010-11-19;   Accepted: 2011-01-15

Abstract: Climate is a critical factor affecting forest ecosystems and their capacity to produce goods and services. Effects of climate change on forests depend on ecosystem-specific factors including dimensions of climate (temperature, precipitation, drought, wind etc.). Available information is not sufficient to support a quantitative assessment of the ecological, social and economic consequences. The present study assessed shifts in forest cover types of Western Himalayan Eco-region (700–4 500 m). 100 randomly selected samples (75 for training and 25 for testing the model), genetic algorithm of rule set parameters and climatic envelopes were used to assess the distribution of five prominent forest cover types (Temperate evergreen, Tropical semi-evergreen, Temperate conifer, Subtropical conifer, and Tropical moist deciduous forests). Modelling was conducted for four different scenarios, current scenario, changed precipitation (8% increase), changed temperature (1.07°C increase), and both changed temperature and precipitation. On increasing precipitation a downward shift in the temperate evergreen and tropical semi-evergreen was observed, while sub-tropical conifer and tropical moist-deciduous forests showed a slight upward shift and temperate conifer showed no shift. On increasing temperature, an upward shift in all forest types was observed except sub-tropical conifer forests without significant changes. When both temperature and precipitation were changed, the actual distribution was maintained and slight upward shift was observed in all the forest types except sub-tropical conifer. It is important to understand the likely impacts of the projected climate change on the forest ecosystems, so that better management and conservation strategies can be adopted for the biodiversity and forest dependent community. Knowledge of impact mechanisms also enables identification and mitigation of some of the conditions that increase vulnerability to climate change in the forest sector.

Keywords: Climate change; forest cover types; shift; western Himalaya; genetic algorithm

The online version is available at http://www.springerlink.com

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Responsible editor: Yu Lei

Introduction

Forests are the vegetation type resulting from the process of succession on land areas except local conditions including climate, soil and biotic factors which arrest development at an earlier seral stage (Bryant 1986; Xu et al. 2009; Geri et al. 2010; Dale et al. 2010; Guo and Werger 2010). Expanding human population and economies are rapidly transforming forest ecosystems (Allen et al. 2010). Climate is another important factor affecting forests (Lasch et al. 2002; Soja et al. 2007). It has an influence on the distribution, structur and productivity (Horikawa et al. 2009) of the forests. Naturalists provide many classification schemes of forest types, but there is a general agreement in considering climatic factors (Champion and Seth 1968; Bryant 1986). Changes in the climate are inevitable and well documented in wide range of literature (IPCC 2007; Miller et al. 2009; Omann et al. 2009; Allen et al. 2010; Lindner et al. 2010). This can severely impact forests, and significant forest dieback can occur (Schickhoff 2000; IPCC 2007; Baker et al. 2010).

There is a probability of shifts in forest biomes due to an increase in temperature and/or changes in water regimes and precipitation pattern (Gasner et al. 2010; Hanewinkel et al. 2010). It has been estimated that with 1°C raise in temperature ecological zones move on earth by 160 km in North-South direction (Thuiller 2007). Many species shifted their ranges to more suitable habitats due to increase in temperature, moving towards higher altitudes (Lenoir et al. 2008; Vennetier and Rippert 2009). Past evidences showed forest migration rates exceed 50 km per century (Noss 2001; Parmesan and Yohe 2003; Woddall et al. 2009). It is expected that tropical forest areas might get seriously affected (Ravindranath et al. 2006; Schickhoff 2008; Suresh et al. 2010).

Geospatial tools and modelling techniques play important role in monitoring the forest ecosystems (Coppin and Bauer 1996; Fraser et al. 2005; Coops et al. 2010; Selkowitz 2010). Modelling can help researchers and planners to make future predictions in time or spatial estimations in a region (Dale et al. 2010). Spa-

tial models have become an important branch of scientific endeavour. In environmental sciences they include weather forecasting, climate models, ground water models, biological ecosystems models, ecological niche models, etc. (Wegener 2001; Jakeman et al. 2008). Models help to formalize our understanding and develop theory about how spatial patterns and ecological processes interacts (Gustafson et al. 2006).

Integrating climate change scenarios in geospatial models can provide insights of shifts in forest cover types. Such shifts are very important to understand for the adaptation planning of the communities dependent on the forest ecosystems. Incidentally around 200 000 villages in India are classified as forest villages; there is obviously large dependence of communities on forest resources (Ravindranath and Sudha 2004). In India, forests accounts for 21% of the geographical area (ISFR 2009). Forests play an important role in environment and economy (Negi 2009). As per study of Ravindranath et al. (2006) around, 77% (A2 scenario) and 68% (B2 scenario) of the forest types in India might shift towards wetter forest types in north-east region and drier forest types in the north-west region in absence of anthropogenic disturbances.

Such estimates are very important for Western Himalayan Eco-region, which represent unique areas for the detection of climatic change and the assessment of climate-related impacts. One reason for this is that, the climate changes rapidly with height over relatively short horizontal distances, so does vegetation and hydrology (Whiteman 2000). Second, the human and forest resource interaction is relatively very high unlike other parts of the country. Finally, mountain systems attract large numbers of people in search of opportunities for recreation and tourism (Godde et al. 2000). It is important to understand the likely impacts of the projected climate change on the forest ecosystems, so that better management and conservation strategies can be adopted for the biodiversity and the forest dependent community. This study was taken because the impacts on the forest types are already visible. Moreover, the recent scientific studies showed impacts on the productivity, forest type shifts, invasions, etc.. This study used remote sensing, GIS and niche modelling to provide an evidence for the expected shift in the forest cover types due to climate change in the western Himalaya (between 700 and 4 500 m altitude).

Materials and methods

Study site

Western Himalayas (altitude of 700–4 500 m) were chosen as the study site. The study area consists of parts of Srinagar, Gangotri national park, Joshimath, Gopeshwar, regions of Pauri and Kumaon. The climatic zone of western Himalaya includes alpine region (above 4 500 m), sub-alpine (3 500–4 500 m), temperate (2 000–3 500 m), sub-tropical (700–2 000 m) and tropical (below 700 m). The climate is from largely semiarid to arid and the growth of trees is limited by moisture stress. Lower western Himalayan temperate forest includes: (1) ban oak forest with *Quercus leucotricophora*, deodar and rhododendron; (2) moru oak forest: *Q. dilatata, Q. leucotricophora, Q. semecarpifolia*, fir, spruce, deodar, blue pine, rhododendron, chestnut, walnut, *Betula* and *Acer*; (3) moist deodar forest extensively developed in western Himalaya and in parts of Nepal; (4) western mixed coniferous forest: fir, spruce and deodar; (5) moist temperate deciduous forest: *Acer, Carpinus, Betula* and *Fraxinus*, and low level blue pine fir. Upper region includes upper oak-fir forest. In trans-Himalayan region dry temperate forest, high level blue pine forest, dry junipers forests are found.

Software

ERDAS Imagine version 9.2 provided by Leica Geosystems was used for satellite pre-processing and analysis. ArcGIS version 9.2 provided by ESRI was used for visual interpretation, and map preparation and analysis. Data processing was carried out on HP xw4550 workstations on Windows XP Professional platform. The facilities available with the Geoinformatics Laboratory at the TERI University, New Delhi were used for this.

Data

Landsat MSS data (path/row 156/39) available with the Global Land Cover Network (GLCN) was used. The datasets are free for the academic and research purposes. For the recent data, IRS P6 LISS III data (path/row 98/50, 9849, 97/50, 97/49) of 2006 was used. The datasets were taken from the archived databank of the Geoinfomratics Laboratory of the TERI University, New Delhi. The Global Land Cover map (2000) prepared for south central Asia using SPOT Vegetation dataset was procured (Agarwal et al. 2003). Climate data for the current time period was obtained from worldclim site. Climate data include annual precipitation, bio 1-bio 19 and altitude. The digital elevation model (DEM) data of Shuttle Radar Topographic Machine (SRTM) was downloaded from the website (http://www.srtm.csi.cgiar.org/, http://www.srtm.usgs.gov/) and imported to Arc-Map for producing the layer maps of aspect and slope.

Data processing

Satellite data for 1976 was downloaded from the Landsat website (www.landsat.org). The IRS P6 LISS III data were borrowed from the National Resource Repository Initiative of National Remote Sensing Centre (NRSC) that is being executed at TERI University. Landsat MSS data were geometrically and radiometrically corrected. IRS P6 LISS III data were processed for geometric and radiometric correction, following procedure used by GLCF while processing Landsat datasets. Onscreen enhancements like local stretching, histogram adjustment, grey level thresholding, filtering and changes in band combinations, etc. were used while interpreting the dataset. The enhancement techniques applied were very locale specific to extract the maximum possible information and delineate the boundaries between the LULC classes.

A strip was subset from the GLC 2000 map, and a vector

boundary was prepared for the study area. The GLC-2000 map prepared for south central Asian region was used (Fig. 1) consists of 45 classes (16 forest and 29 non-forest) based on FAO land cover classification scheme (LCCS). In the present study, five prominent forest classes, i.e. temperate evergreen, tropical semi-evergreen, sub-tropical conifer, temperate conifer and tropical moist deciduous forests, were used for further investigation, modelling and predictive analysis in light of climate change.

Digital Elevation Model (DEM) from SRTM data was also clipped using the boundary. DEM was used to obtain aspect and slope. The data were converted from image (.img) file to GRID file. The climate data (Bio 1- Bio 19, and Precipitation (12 months)) obtained from worldclim site (http://www.worldclim.org/) was converted from .BIL to GRID format and projected to Geographic Lat/Lon, WGS 84, meters. The study area was clipped from the data. The precipitation for all the 12 months was added to get the annual precipitation. The clipped climate data (19 layers), LULC map (GLC-2000), precipitation, DEM, aspect, and slope were stacked together. Principal Component Analysis (PCA) was performed on the stacked layers for selecting most significant layers from the entire data. Bases on the loading factors, environmental layers selected for niche modelling were altitude, aspect, Bio 1, Bio 12, and Bio 16.

Ecological niche model

Distribution of forest types were projected using ecological niche modelling by Genetic Algorithm of Rule-set Parameters (GARP) which is based on assumptions that ‘ecological niches are stable’ uses different rule-sets to determine the ecological dimensions of the species in a landscape (Peterson and Vieglias 2001). GARP considers population as a set of individual rules for predicting presence or absence of a species at a cell. Present data were accepted as point location and environmental layers in RAW format, and this format can be generated from dataset manager which converts ASCII into RAW. Rules are composed of chromosomes that encode the coefficients for variables in the model. For example, each individual in a population has “chromosomes” for abiotic factors and candidate species. GARP utilizes a rule record that maintains a set of the best and uniquely different. A confusion or error matrix are created that shows the relative proportions of omissions or commissions errors.

Projecting forest cover distribution

According to IPCC Fourth Assessment Report, the precipitation in western Himalayan region is expected to increase by 8% and temperature by 1.07°C for 2010–2039 (B2 scenario). For understanding the future distribution of the forest types, the current precipitation value was raised by 8%, for example:

$$P_{2010-2039} = P_{present} + [0.08 \times P_{present}] \quad (1)$$

Where, $P_{2010-2039}$ is the precipitation value for the time period of 2010–2039, $P_{present}$ is the current precipitation value, and 0.08 is the increase predicted by IPCC.

The change in temperature is calculated using following set of equations.

$$\Delta T = 1.07 - (0.00649 \times Altitude) \quad (2)$$

$$T_{new} = T_{present} + \Delta T \quad (3)$$

Where, T_{new} is the new temperature value for the time period of 2010–2039, $T_{present}$ is the current temperature value, 1.07 is the predicted raise in the temperature for 2010–2039 by IPCC, and 0.00649 is the lapse rate.

For assessing the present distribution, 100 randomly generated points from GLC 200 were used along with the climatic variables. 75 points were selected for the training and the other 25 points were selecting for testing and validating the model. The modelling was carried out on four different combinations: First, the present (current) distribution by using the climatic envelopes; Second, increasing the precipitation (by 8%) as per the IPCC prediction; Third, increasing the temperature (by 1.07°C) as per the IPCC prediction and adjusting the values as per orography and lapse rate; Fourth, increasing both precipitation (by 8%) and temperature (by 1.07°C) as discussed above.

Results and discussion

Visual analysis of temporal satellite data

Satellite data of 1976 and 2005 were visually compared to find out the variation in the forest cover type. This comparison was carried out at the alpine zone and timber line to identify the impact of climate change in past three decades. Though the comparison was carried out for the entire study region, four prominent cases selected randomly were explained. First site was located at an altitude of 4 434 m of 30°12′26.04″ N and 79°58′26.74″ E (Fig. 2a). At this altitude tropical semi-evergreen and sub-tropical coniferous forests were found, and they showed no significant changes in two time periods. A few pockets of change could be identified showing impact of anthropogenic activities. At certain areas, a degree of dryness could be interpreted while comparing two datasets. Second site was located at 3 555 m of 30°23′47.72″ N, 80°10′04.74″ E (Fig. 2b). At this altitude, tropical moist deciduous, semi-evergreen, temperate conifer and sub-tropical conifer forest types were present. There were also no significant changes. However, visual variation could be detected on enhancing the data but no changes in distribution could be interpreted. Third site was located at 2 850 m altitude of 30°38′18.63″ N, 79°49′37.79″ E (Fig. 2c). This location is consisted of tropical semi-evergreen, tropical moist deciduous, temperate conifer and sub-tropical conifer forests. Also, visual changes were not observed at this elevation. Fourth site was located at an altitude of 1 100 m of 30°14′02.48″ N, 79°14′ 52.91″ E (Fig. 2d). Moist deciduous, tropical semi-evergreen forest types were dominant. Through visual interpretation of the satellite images from the two time data, there were significant

changes observed in these forest types at this altitude. Through visual interpretation of the maps there were no significant changes observed to predict the distribution of the forest types by niche modelling.

Shifts in forest cover types due to climate change

The ecological niche modelling provided predicted maps of presence of the forest types on spatial domain. These Boolean maps were later stacked in GIS domain to prepare the maps of potential distribution of a forest cover type. The best combinations of the predicted maps were selected based on accuracy assessment table (confusion matrix). The best model outputs are clustered in the regions of minimum omission and moderate commission. The summary of the shifts observed is given in Table 1.

Table 1. Shifts in forest cover type distribution in different climate change scenario

Forest cover type	Current distribution (m)	Increased precipitation (IP)	Increased temperature (IT)	The sum of IP and IT
Temperate evergreen	>4500	↓	↑	↑
Tropical semi-evergreen	3000–4500 & ≥ 4500	↑	o	~
Temperature conifer	3000–4500 & ≥ 4500	~	↑	~
Sub-tropical conifer	3000–45000	↑	~	~
Tropical moist-deciduous	900–1800 & 1800–3000	↑	↑	↑

NB: ↓ downward shift, ↑ upward shift, ~ no significant change, o cluttered distribution.

Temperate Evergreen

These forest types lie above the altitude of 4 500 m in their current potential distribution. When the precipitation is increased by 8%, current distribution is maintained and a downward shift towards 1 800–3 000 m. When the temperature is raised, the current distribution is maintained with an upward shift. With a change in both temperature and precipitation, the current potential distribution is maintained and a slight upward shift is observed. These forests are described as dense evergreen trees with large girth and a medium height. They have large branching crowns with mosses, ferns, aroids and other epiphytes. A small proportion of deciduous species occur at higher altitude. Dense and uniform dwarf bamboo undergrowth is also found at higher altitudes with covering large areas.

Tropical semi-evergreen:

The current potential distribution of this forest type lies in between 3 000 m and 4 500 m and also ≥ 4 500 m in altitude. When precipitation is raised the forest type shifted a little downwards in the altitudinal zone of 3 000–4 500 m. When the temperature is raised, the forest type was cluttered around 4 500 m. Both the factors are changed, and then the potential distribution was found to increase in between 3 000 m and 4 500 m. These forests occur between evergreen and moist deciduous forests. The species in this forest types are *Dipterocarpus* spp., *Shorea* spp., *Mesua ferrea* mixed with *Terminalia* spp., *Bombax cieba, Mangifera indica, Michelia champaca* and *Hopea parviflora*. The growth is poor in semi-evergreen forests compared to evergreen forests. Other species here are bamboos, canes, ferns, and epiphytes.

Temperate conifer

This forest type is located at 3 000–4 500 m and a few scattered patches above 4 500 m. No significant change has been observed in the actual distribution above 4 500 m, when the precipitation is changed. When temperature increases, the potential distribution is above 4 500 m altitude and also an upward shift is observed. With the increase in both parameters the actual potential distribution is retained, and it also spreads to both higher and lower altitudes. In western Himalaya, these forests are around 3 000 m except in the areas with rainfall below 1 000 mm. There is an extensive development of coniferous forests with a rainfall between 1 000 and 2 500 mm. These are dominated by *Pinus wallichiana* in lower form and *Abies pindrow* and *Picea smithiana* in upper forms. *Cupessus torulosa*, *Alnus nepalensis* and *Pinus wallichiana* colonise the new sites. There are *Pinus gerardiana, Cedrus deodara, Juniperus marcopoda*, *J. wallichiana, Abies* spp. and *Picea* spp. in the dry temperate zone. The species are mainly dependent on altitude and aspect. Deciduous shrubby undergrowth is also found.

Sub-tropical conifer

The current potential distribution was found to lie in 3 000–4 500 m in altitude. When the precipitation is raised, current potential distribution is same and a little shift towards >4 500 m is also observed. When temperature is raised, threr is no significant change in the distribution. Increase in both temperature and precipitation resulted in no significant change in the distribution. These forests are pure associations of pine forest. There is practically no undergrowth and shrubs. Broad-leaved trees form an under-wood when there is a favourable moisture condition. A grass and soil cover is present with a number of annual herbs flowering in rainy season.

Tropical moist-deciduous forest

The current potential distribution is between 900–1 800 m and 1 800–3 000 m in altitude. Change in precipitation results in a little upward shift towards 3 000–4 500 m, but the current distribution is also maintained. With the change in temperature an upward shift is observed towards 3 000–4 500 m and above 4 500 m. If both temperature and precipitation is changed, there is a small upward shift in between 1 800–3 000 m and also towards 3 000–4 500 m. These occur in the foothills of Himalaya. These are commonly found in areas with rainfall between 1 500 mm

and 2 000 mm in a dry season of four to six months. The most common species are *Shorea robusta* and *Tectona grandis*.

Conclusion

The main objective of the study was to analyse the shift in forest cover types in Western Himalayan Eco-region (700–4 500 m altitude) in light of climate change. Satellite remote sensing imageries were used for visualisation and identification of the changes in forest cover between 1976 and 2005. The entire study area was visually scanned at 1: 50 000 scale. Four sites were randomly selected at different altitudes, i.e. 4 434 m, 3 555 m, 2 850 m and 1 100 m to demonstrate the hypothesis of forest cover change in past three decades. There were no significant changes in the spectral response, and pattern and distribution of forest types.

For ecological niche modelling training dataset was extracted from the Global Land Cover-2000 map of South Central Asia prepared using SPOT 4 Vegetation data. Five dominant forest types used for modelling were temperate evergreen, tropical semi-evergreen, temperate conifer, sub-tropical conifer and tropical moist deciduous forests. Other classes present at higher altitudes were alpine grassland, desert grassland, alpine meadow and snow, and at lower altitudes were irrigated agriculture, irrigated intensive agriculture, settlements and water body.

The potential distribution of the five forest types selected from GLC-2000 map was predicted based on GARP using randomly generated presence/absence data and the current climatic dataset obtained from Worldclim site. The modelling was conducted for three different scenarios of climate change. Firstly, the current potential distribution was predicted based on the GCPs points generated from the forest cover type map. Secondly, the prediction was done by increasing precipitation by 8%. Third, the model was run by increasing temperature. Finally, the prediction was done by changing both temperature and precipitation.

With changes in temperature and precipitation from current climate to B1 scenario (IPCC) for 2010–2039, the potential distribution was predicted. On increasing precipitation, there was a downward shift in the temperate evergreen and tropical semi-evergreen while sub-tropical conifer and tropical moist-deciduous forests showed a slight upward shift, and temperate conifer showed no shift. On increasing temperature, an upward shift in temperate evergreen, tropical semi-evergreen, temperate conifer and tropical moist deciduous forests was observed, but sub-tropical conifer forests didn't show any significant changes. When both the parameters were changed, the actual distribution was maintained and there was slight upward shift in temperate evergreen, tropical semi-evergreen, temperate conifer and tropical moist deciduous forests except sub-tropical conifer. Results of several studies indicate that geographical shift of timberline towards upper limit is less frequent as expected (Lloyd and Graumlich 1997, Cullen et al. 2001, Camarero and Gutierrez 2004). Response of forest cover to changing environment can also take place by changes in growth, growth forms, regeneration and spatial heterogeneity. However, the observed result depends on the scale of study (Holtmeier and Broll 2005).

Geospatial tools help in assessing the pattern and distribution of forest types at spatial level. The information obtained from these tools can be used for planning natural landscapes, biodiversity conservation and for natural resources management. Satellite data can help policy makers to assess the current situation, analyse long-term trends and help in sustainable management of forest resources. In this study, only five environmental layers were used for predicting the potential distribution. Information from other factors that may affect the potential distribution of the forest types can also be included for better prediction.

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